A METHOD AND SYSTEM FOR REDUCING POWER CONSUMPTION IN A ROTATABLE MEDIA DATA STORAGE DEVICE

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A METHOD AND SYSTEM FOR REDUCING POWER CONSUMPTION IN A ROTATABLE MEDIA DATA STORAGE DEVICE

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Technical Field:

[0001] The present invention relates to rotatable media data storage devices, as for example magnetic or optical hard disk drive technology, and power consumption of rotatable media data storage devices.

Background:

[0002] Over the past few years, notebook computers have become progressively thinner and lighter, and battery technology has improved significantly; but, though both thinner and lighter, notebook computers have incorporated ever-more powerful CPU's, larger and higher resolution screens, more memory and higher capacity hard disk drives. Feature-rich models include a number of peripherals such as high-speed CD-ROM drives, DVD drives, fax/modem capability, and a multitude of different plug-in PC cards. Each of these features and improvements creates demand for power from system batteries. Many portable electronics, such as MP3 players and personal digital assistants, now use rotatable data storage devices as well, and by their nature and size place great demands for power on batteries.

[0003] Many manufacturers of rotatable data storage devices reduce demand on batteries by employing power savings schemes; for example, many manufacturers ramp down and stop a rotating

storage medium after a period of inactivity. This scheme comes at a cost to performance - the medium must be spun up from standstill before information can be accessed from the medium.

Brief Description of the Figures

[0004] Further details of embodiments of the present invention are explained with the help of the attached drawings in which:

[0005] **FIG. 1** is a control schematic of a typical hard disk drive for applying a method in accordance with one embodiment of the present invention;

[0006] **FIG. 2** is a schematic of a linear mode spindle motor driver used in the typical hard disk drive of **FIG. 1**;

[0007] **FIG. 3A** is a schematic of a switch mode spindle motor driver used in the typical hard disk drive of **FIG. 1**; and

[0008] **FIG. 3B** is a schematic of a pulse width modulation (PWM) controller used in the spindle motor driver of **FIG. 3A**.

Detailed Description

[0009] Methods and systems in accordance with embodiments of the present invention can provide for reduced power consumption in rotatable media data storage devices. **FIG. 1** is a control schematic of a typical hard disk drive **100** for applying a method in accordance with one embodiment of the present invention. The hard disk drive **100** includes at least one rotatable data storage medium **102** capable of storing information on at least one surface. Numbers of disks and surfaces can vary

by hard disk drive. In a magnetic hard disk drive as described below, the at least one storage medium **102** is a magnetic disk. A closed loop servo system can include a rotary actuator having an arm **106** for positioning a head **104** over selected tracks of the disk **102** for reading or writing, or for moving the head **104** to a selected track during a seek operation. In one embodiment, the head **104** is a magnetic transducer adapted to read data from and write data to the disk **102**. In another embodiment, the head **104** includes separate read elements and write elements. The separate read element can be a magneto-resistive head **104**, also known as an MR head **104**. It will be understood that multiple head **104** configurations can be used.

[0010] The servo system can include a driver for driving a voice coil motor (VCM) **108** for rotating the actuator arm **106**, a driver for driving a spindle motor **112** for rotating the disk(s) **102**, a microprocessor **120** for controlling the VCM driver **108** and the spindle motor driver **112**, and a disk controller **128** for receiving information from a host **122** and for controlling many disk functions. A host can be any device, apparatus, or system capable of utilizing the data storage device, such as a personal computer or Web server. In some embodiments, the disk controller **128** can include an interface controller for communicating with a host **122**, while in other embodiments a separate interface controller can be used. The microprocessor **120** can also include a servo controller, which can exist as circuitry within the hard disk drive **100** or as an algorithm resident in the microprocessor **120**, or as a combination thereof. In other embodiments, an independent servo controller can be used. In still other embodiments, the servo controller, VCM driver **108**, and spindle motor driver **112** can be integrated into a single application specific integrated circuit (ASIC). One

of ordinary skill in the art can appreciate the different means for controlling the spindle motor and the VCM .

[0011] The microprocessor **120** can include integrated memory (such as cache memory), or the microprocessor **120** can be electrically connected with external memory (for example, static random access memory (SRAM) **110** or alternatively dynamic random access memory (DRAM)). The disk controller **128** provides user data to a read/write channel **114**, which sends signals to a current amplifier or preamp **116** to be written to the disk(s) **102**. The disk controller **128** can also send servo signals to the microprocessor **120.** A disk controller **128** can include a memory controller for interfacing with buffer memory **118**. In one embodiment, the buffer memory **118** can be DRAM.

[0012] The microprocessor **120** can command current from the spindle motor driver **112** to drive the spindle motor, thereby rotating the disk(s) **102**. A control structure of the spindle motor driver **112** is typically configured to operate exclusively in either linear mode or switch mode to provide the commanded current to windings of the spindle motor. A similar driver stage can be used for spindle motor drivers **112** having either a linear mode or a switch mode configuration. A pre-driver stage control structure determines whether the instantaneous current is driven to a specific target (as in linear mode) or the instantaneous current is driven in a limit cycle where the average current value is approximately the specific target value with controlled maximum peak current values (as in switch mode).

[0013] **FIG. 2** is a simplified schematic of a portion of one example of a spindle motor driver **112** configured to operate in linear mode (hereafter called a linear mode driver) **212**, showing exemplary elements for providing current to the spindle windings **240** including the driver stage **250**,

a commutation sequencer **242**, an operational amplifier stage **254**, a current feedback stage **252**, and a voltage centering bias structure **256**. As mentioned above, a similar driver stage **250** can be used for either the linear mode driver or a spindle motor driver **112** configured to operate in switch mode (hereafter called a switch mode driver), and in this example is shown to comprise a MOSFET triplet "H-bridge". Alternatively, the driver stage **250** can comprise a number of different components fabricated using a number of different manufacturing techniques. One of ordinary skill in the art can appreciate the different configurations for the driver stage.

[0014] Immediately preceding the driver stage **250** in the linear mode driver is the current feedback stage **252** where the current in each individual MOSFET transistor **250a-f** is controlled via a current mirror control structure **252a-f**.

[0015] The stage preceding the current feedback stage **252** is the operational amplifier stage **254**, typically only implemented in a linear mode driver. The output of an operational amplifier **254x-z** is a signal targeting a continuous current value. Each operational amplifier **254x-z** generates a pair of voltages for each phase winding that are applied to current mirror transistors **252a-f** in the current feedback stage **252** for control of driver stage transistor current. The input to the operational amplifier stage **254** can be controlled by a switch **256** associated with the commutation sequencer **242** that typically guides the commanded current signals **244** to two of the three operational amplifiers **254x-z** in the operational amplifier stage **254** to enable current flow in two of the three windings **240**, thereby maximizing the peak positive torque produced by the spindle motor. The commutation sequencer **242** sequences through commutation states, which can correspond to sets

of torque curves representing the functional relationship between torque, current flow and angular position.

[0016] The voltage centering bias structure **256** is selectively multiplexed (via a switch) to active transistor pairs (e.g. **250a** and **250b**) to center the output voltage of the driven windings to the power supply voltage and to keep the output impedance of the undriven transistor pair high. This balances the power dissipation in the driver stage **250** evenly between the upper and lower FET transistors in each transistor pair.

[0017] The schematic shown in **FIG. 2** is merely one example of a schematic for a linear mode driver. A linear mode driver can include additional or fewer elements, while achieving similar results. One of ordinary skill in the art can appreciate the different configurations for achieving current control.

[0018] **FIG. 3A** is a simplified schematic of a portion of one example of a switch mode driver **312**, showing exemplary elements for providing power to the spindle windings **240**, including the driver stage **250**, a commutation sequencer **242**, a pulse width modulation (PWM) controller **362**, a driver controller **358**, and a current feedback loop **360**. The output of the driver controller **358** is a state where the individual transistors **250a-f** are either fully turned on (saturated) or fully turned off, rather than a continuous current value.

[0019] As with the linear mode driver **212**, commutation states can correspond to a set of torque curves. The commutation sequencer **242** sequences through the commutation states to control switching elements **250a-f** that drive the spindle motor to maximize the peak positive torque produced by the spindle motor. The commutation sequencer **242** switches on two power transistors

250a-f on opposite legs of windings **240** during each of the commutation states (via driver controller **358**). Thus, there is one floating winding for the spindle motor during each of the commutation states.

[0020] The PWM controller **362** monitors the instantaneous current flow in the driver stage **250** and when the current builds up to a value greater than a programmable threshold the PWM controller **362** overrides the commutation sequencer **242** and the driver stage **250** is turned off via the driver controller **358**. In this way, the maximum current in the limit cycle profile of the spindle current is very well controlled. Maximum current control is used to control the average value of the spindle current, and by extension to control the speed of the spindle.

[0021] **FIG. 3B** illustrates in greater detail components that comprise the PWM controller **362**. The PWM controller **362** comprises a voltage comparator **364** and a one-shot timer **366**. The one-shot timer **366** allows current flow **368** in the spindle windings to increase at a rate limited by the inductance of the spindle winding **240**. When the current **368** in the spindle winding increases above the command current threshold, the voltage comparator **364** is tripped, setting the one-shot timer **366**. When the one-shot timer **366** is set, the driver stage transistors **250a-f** are disabled, causing the current **368** in the spindle winding to drop below the command current threshold. When the one-shot timer **366** times out, the voltage comparator **364** has cleared (i.e. is no longer in a "tripped" state), and the process is repeated, causing a limit cycle in the spindle current with well controlled maximum current peaks. In other embodiments, the one-shot timer **366** can control minimum current dips rather than maximum current peaks by enabling the driver stage transistors

250a-f when the current drops below a minimum current dip. One of ordinary skill in the art can appreciate the different methods by which a limit cycle can be controlled.

[0022] In principle, a switch mode driver is a very efficient driver. By continually shorting the power supply across the load, a relatively precise current having a saw-tooth pattern can be obtained. Typically, faster switching produces smaller saw-tooths, resulting in a smoother overall current plot. A switch mode driver **312** having no resistance dissipates no power and all power losses are across the load (the spindle). In reality, there are some power losses associated with switching due to resistance in the switch mode driver **312** and per-switch energy dissipation, but typically the switch mode driver **312** dissipates less power than a linear mode driver **212**. Inaccuracies in the one-shot time value and/or noise in the current feedback signal can result in substantial deviations in the instantaneous current values that are not repeatable. These inaccuracies are commonly minimized in a switch mode driver **312** by switching at a very high frequency, providing more accurate control over the current delivered to the load but at the same time as the frequency of switching increases, switching losses increase and the power dissipated in the switch mode driver **312** increases. Further, electrical interference can be generated by switching, potentially interfering with the heads **104** during seeks and read/write operations.

[0023] The schematics shown in **FIGs. 3A** and **B** are merely examples of switch mode driver configurations. One of ordinary skill in the art can appreciate the different configurations for achieving current control.

[0024] In one embodiment, a method in accordance with the present invention can be used to achieve power savings comparable with switch mode drivers, for example when idle, and achieve

current control associated with linear mode drivers, for example during read/write operations and seeks. The method can be applied to a hard disk drive **100** configured with a linear mode driver **212** (as shown in **FIG 2**). The method comprises a low power mode activated when the head **104** is idle; that is, not reading or writing to or from the medium. In a low power mode, the microprocessor **120** commands a grossly exaggerated current **244** from the linear mode driver **212**, saturating the operational amplifier stage **254**. At some time interval later, the microprocessor **120** "turns off" the driver stage **250** by commanding zero current from the operational amplifier stage **254**. The microprocessor **120** alternates between saturating the operational amplifier stage **254** and turning the driver stage **250** off at a limit cycle. When the head **104** receives a command, the hard disk drive **100** returns to linear mode and the operational amplifier stage **254** is commanded to a current for achieving a target spindle speed.

[0025] During low power mode, the linear mode driver **212** can resemble a switch mode driver **312**. However, the linear mode driver **212** typically has a continuous current feedback loop coupled to each individual output transistor (the current mirror stage **252**) and does not include a single current feedback loop **360**. The limit cycle for the linear mode driver **212** can be based on a back EMF voltage detector (not shown). The microprocessor **120** can use timing pulses from the back EMF voltage detector to create control signals defining the limit cycle. The limit cycle for low power mode typically provides coarser current control. Beneficially, this can result in lower power losses attributable to switching. By applying the method, the hard disk drive can reduce the power consumed by the spindle motor driver **112** during periods when possible electrical interference from

changes in current and/or imprecise spindle speed control do not interfere with the operation of the hard disk drive **100**.

[0026] A system for applying the method in accordance with one embodiment of the present invention can include the hard disk drive **100** described above including read-only memory (ROM) for storing firmware adapted to generate commands for current from the linear mode driver **212** such that the linear mode driver **212** can operate in low power mode. In a run mode of operation, either the microprocessor **120** or the disk controller **128** controls all of the spindle functions except the function of flagging the disk controller **128** to the existence of a spindle speed fault. For operations other than run mode (i.e. alignment, start-up, brake, and low power mode) the firmware is used for direct, real-time control of the spindle current. In low power mode, the firmware can receive timing pulses based on back-EMF measurements of spindle speed. The firmware can then generate command currents for controlling spindle speed based on the timing pulses. The ROM used to store the firmware can be programmable read-only memory (PROM), or electrically erasable programmable read-only memory (EEPROM), etc, or alternatively, the firmware can be stored on a medium other than ROM, for example FLASH memory.

[0027] In other embodiments, a system for applying the method in accordance with the present invention can include an ASIC comprising a linear mode driver **212** and a spindle speed controller (not shown), wherein the spindle speed controller can modulate the current in linear mode to maintain the spindle speed at a constant desired value without requiring current commands from the microprocessor **120**. As described above, the system can include ROM or other medium for storing firmware. In low power mode, the firmware creates commands for current and sends the

commands to the ASIC, overriding the spindle speed controller and activating the low power mode described above. In still other embodiments, the host **122** comprises the firmware and sends the commands to the ASIC via the serial port.

[0028] In another embodiment, a method in accordance with the present invention can be used to achieve additional power savings with a switch mode driver **312**, for example by increasing the limit cycle when idle and decreasing the limit cycle during read and write operations, thereby targeting the need for maximum current control. The method comprises a low power mode activated when the head **104** is idle, that is, not reading or writing to or from a medium. In low power mode, a programmable threshold for the PWM controller **362** can be increased to increase the limit cycle, thereby reducing the switch rate of the switch mode driver **312**. The reduced switch rate results in lower switching losses. When the head **104** receives a command, the programmable threshold of the PWM controller **362** is decreased, decreasing the limit cycle of the switching. A system for applying the method in accordance with one embodiment of the present invention can comprise the hard disk drive **100** described above including ROM or other medium for storing firmware adapted to reprogram the programmable threshold of the PWM controller **362**. In low power mode, the firmware can be used to re-program the programmable threshold of the PWM controller **362** so that the limit cycle is longer.

[0029] In still other embodiments, a method in accordance with the present invention can be used to achieve power savings in the VCM. The method can be applied to a hard disk drive **100** configured with a VCM driver **108** operating in linear mode. In the VCM, current is provided to a single voice coil, and the VCM driver **108** can have a simpler structure than that of the linear mode

driver **212** for the spindle. The method comprises a low power mode activated when the head **104** is idle; that is, not reading or writing to or from the medium. In a low power mode, the microprocessor **120** commands a grossly exaggerated current from the VCM driver **108**. At some time interval later, the microprocessor **120** "turns off" the VCM driver **108** by commanding zero current. The microprocessor **120** alternates between saturating and turning off the VCM driver **108** at a limit cycle. When the head **104** receives a command, the hard disk drive **100** returns to linear mode and the VCM driver **108** is commanded to a current to pivot the rotary actuator.

[0030] The foregoing description of preferred embodiments of the present invention has been provided for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations will be apparent to one of ordinary skill in the relevant arts. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, thereby enabling others skilled in the art to understand the invention for various embodiments and with various modifications that are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims and their equivalence.